Measuring the Implicit Value of Subsurface Mineral Rights in Eastern Ohio

A Hedonic Model of Agricultural Land Sales in Belmont County

Undergraduate Honors Thesis

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Abstract

Shale gas development has proliferated in eastern Ohio, leading to questions about the economic impacts of the influx of entities seeking to explore and extract minerals in the region. A major source of economic gain for landowners in these areas is direct revenue from the purchasing and leasing of mineral rights by the mineral extraction industry. However, there is a history of mineral development in Eastern Ohio, implying the existence of split estates, situations in which the surface and subsurface rights for a given parcel of land are separately owned. While mineral rights are directly traded in the market, their implicit value as derived from the land and housing market may differ from this explicit market price. This paper attempts to evaluate the willingness-to-pay for a land parcel severed from the subsurface rights by estimating a hedonic model of agricultural land sales in Belmont County, Ohio. The findings of this research are inconclusive; while the dummy variable indicating the existence of a split estate is insignificant in all hedonic model specifications, measurement error and potential endogeneity may bias this result. However, other findings of the research corroborate the findings of literature in this subject area. This paper discovers a significant, positive relationship between permitted well density and sales price, and a consistently negative relationship between producing well density and sales price. These findings may indicate the existence of speculation in the land market, i.e., situations in which land in regions expecting payments for royalties and mineral rights appreciate in value, but those within the county where the development phase of shale production has passed are depreciating in value. Further research should focus on controlling for endogeneity and exploring interesting behavior discovered in land sales records, such as the observed propensity to buy full land parcels and split the estate shortly after sale.

Introduction

A major market restructuring is underway in the United States; after decades of increasing natural gas imports, the United States is projected to become a net exporter of natural gas by 2020 (Annual Energy Outlook 2015). This shift can be mostly attributed to recent innovations in the mineral extraction industry. In the early 2000's, a combination of previously utilized drilling methods, horizontal drilling and hydraulic fracturing, were applied in tandem successfully to elicit economically viable production of natural gas from gas reservoirs locked in tight shale rock formations. This development has spurred a massive increase in natural gas exploration throughout the United States. The predicted economic benefits, and potential external costs, from shale development in the region vary in the literature (Kinnaman 2011) (Mason, Muehlenbachs, and Olmstead 2015); however, for holders of oil and gas rights in the region, shale development can bring direct sources of revenue from the leasing of these rights to prospective drillers. In some regions, including Eastern Ohio, historical development of subsurface resources led to the proliferation of split estates, parcels for which the subsurface rights were split from the surface rights due to past leasing or sale of mineral rights. Using data on surface and subsurface rights transfers, this paper utilizes a hedonic analysis of agricultural land sales to attempt to discover the implicit land market value of mineral rights ownership in Belmont County, Ohio.

Many papers have explored the impacts of gas development on local housing and land markets. Muehlenbachs (2012) and Gopalakrishnan and Klaiber (2013) both utilize hedonic frameworks to analyze housing market impacts of local shale gas development in Western Pennsylvania. Effects were found to be dependent on the surrounding area of the house, as well as the source of water. Boslett, Guilfoos, and Lang (2016) exploit changes in expectations due to a moratorium placed on development of shale gas in New York to evaluate housing market impacts in a difference-in-difference framework. A significant appreciation of home values is found in areas with shale development. Focusing on the agricultural land market, Weber and Hitaj (2014) also use a hedonic framework to find modest appreciate during the permitting stages of gas production, with insignificant findings during latter stages of production. Timmins and Vissing (2015) is the first to control for mineral rights ownership, using a dual gradient hedonic model to value various lease clauses when subsurface rights are either owned or split from the surface owner.

The purpose of this paper is to value the ownership of mineral rights within the agricultural land market. Previous studies have explored general impacts of gas development on real estate markets, but limited research has focused on the impact of subsurface rights ownership on these impacts. Indeed, much of the literature in the topic area has acknowledged that the major omitted variable in their datasets was reliable leasing and mineral ownership data. This paper attempts to incorporate mineral rights ownership into its analysis, in order to capture the implicit value these rights have in land sales. This provides two main contributions to the literature. Firstly, this paper is one of the first attempts to fully incorporate mineral rights ownership into the hedonic analysis of land and housing prices of shale regions. Secondly, this paper provides policy makers with information on how the shale gas boom is affecting land prices over different phases of development in Eastern Ohio. This is important, as there have been few attempts at analyzing the real estate impacts of shale development in an Eastern Ohio setting.

This paper finds no significant result indicating that a split estate impacts the price of agricultural land. This result, however, is potentially biased due to endogeneity in the split estate variable, as well as measurement errors in the dataset. Difficulties in identifying land parcels with split estates leads to a large underestimate of its effects on land prices. Alternatively, variables for permitted well density in the area surrounding a land sale were found to be significant and positive, while variables for producing well density were almost significant and negative in sign. This finding corroborates the results of Weber and Hitaj (2014), indicating that most appreciation occurs during the permitting stages of shale development, with relative depreciation occurring in regions of the county where leasing and permitting have likely ceased.

The first section of the paper provides a background of shale gas development in the United States and in Ohio. This is followed by an extended review of the pertinent literature of the topic area, including a theoretical overview of hedonic valuation. A brief description of the area of study, Belmont County, Ohio, precedes a description of the data sourced and utilized in this research. The specific methodology of this hedonic analysis is in the next section, with the corresponding results from this analysis reported afterwards. Finally, the results of the paper are interpreted in the discussion section, with concluding remarks at the end of this paper.

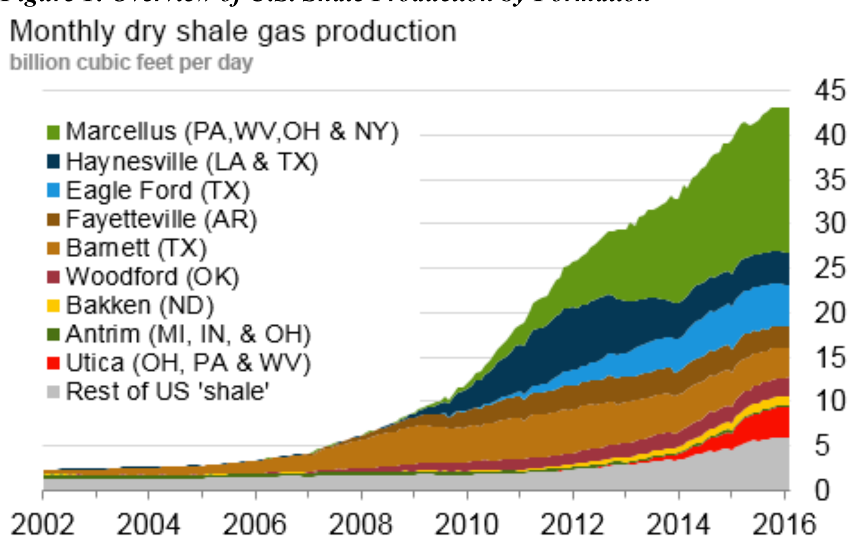
Background: "Unconventional" and Shale Gas Development

The expansion and subsequent boom in natural gas production in the United States can be traced to a combination of public and private interest in developing "unconventional" sources of natural gas for domestic consumption (Wang and Krupnick 2015). Unconventional sources of natural gas are those that require special extraction techniques for recovery of minerals; examples include coal bed methane, tight sands gas, and shale gas (Yergin 2011)(EPA 2016). Extracting natural gas from shale formations was an economically infeasible venture for most of the 20th century, with limited spending on shale exploration and technological research coming from the private sector. However, the existence of large reserves of gas locked away in shale plays was commonly known by the industry and by the United States government (Yergin 2011). Public research into technological improvements geared towards unconventional gas resources were prompted as gas shortages in the 1970's facilitated a public interest in maintaining domestic supply. This public research had direct implications on the technological feasibility of shale gas extraction; microseismic fracture mapping and hydro-fracturing technologies, two of the most important technologies in stimulating the shale boom, were partially developed by the United States Department of Energy through federal research spending (NETL 2007). The Natural Gas Policy Act of 1978 removed many of the market barriers in the gas industry, such as price controls, allowing for the development of a burgeoning natural gas market within the nation. Additionally, financial incentives for shale extraction were established in this legislation and subsequent others, providing more stimuli for the nascent unconventional gas industry (Wang and Krupnick 2015).

Private interest in unconventional production was limited, until Mitchell Energy and Development, a natural gas firm operating in Texas, proved the economic feasibility and production potential of extracting gas from these sources. Focusing its efforts on the Barnett Shale play in Texas, Mitchell worked throughout the 1990's to increase the productivity of its shale wells, spending heavily on research and development in order to continue productivity gains. The Barnett play had been mostly abandoned by competing firms by the late 1990's, and almost all shale development occurring in the United States at the time was centered on the Michigan shale basin in the Midwest (Wang and Krupnick 2015). The firm, due to a long-term contract with a national pipeline firm, had the financial stability and liquidity to tackle such a heavy R&D project, a rarity in a relatively competitive gas extraction industry (Wang and Krupnick 2015). By 2001, Mitchell had improved its production process, completing over 200 wells in the Barnett play utilizing shale production techniques. Interest in the Barnett exploded and competitors flocked to the market to extract gas utilizing "fracking" techniques.

Since then, shale gas has restructured the United States energy and electricity market. In early 2016, for the first time since the mass electrification of the country, natural gas overtook coal as the leading energy source for electricity in the United States, reducing the carbon footprint of the US electricity sector (EIA 2016). Continued pressures to reduce coal consumption, higher efficiencies in natural gas power plants, and productivity gains in the shale gas industry signal continued development of shale gas resources in the coming decades. Spatially, exploration has branched from its beginnings in Central Texas and has proliferated across various United States shale plays (see figure 1).

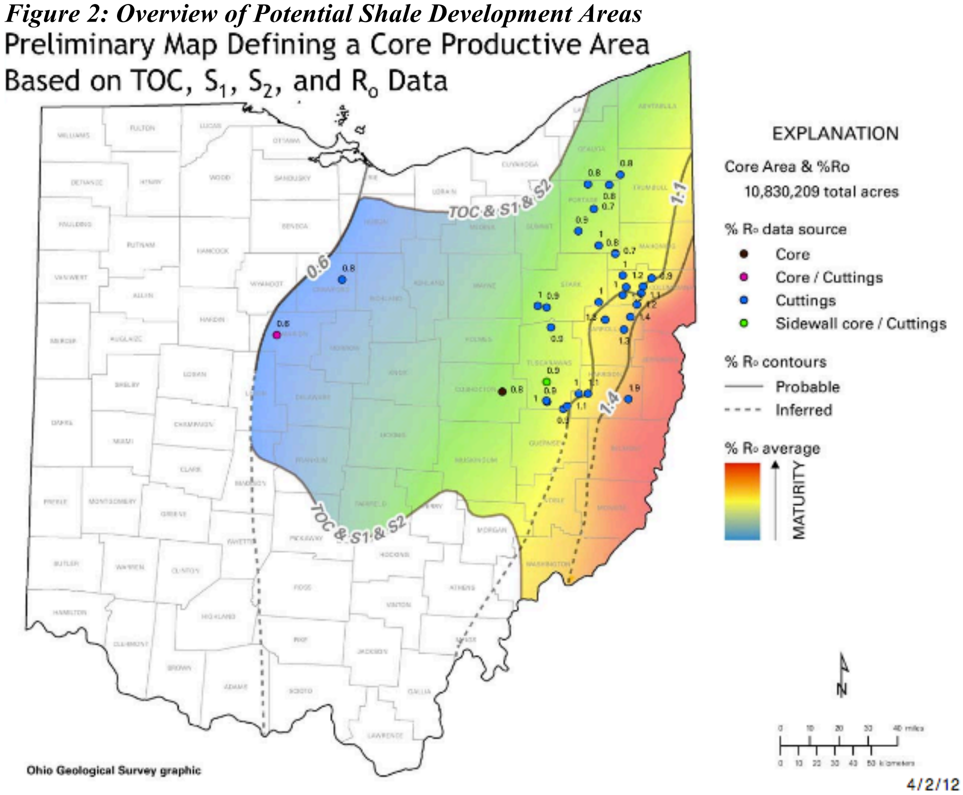
Figure 1: Overview of U.S. Shale Production by Formation



Source: Energy Information Administration Monthly Natural Gas Report (2016)

While much early expansion occurred in Texas, Louisiana, and Oklahoma, the Marcellus shale play quickly became the center of shale gas production in the United States. This massive shale formation, located about 4000 feet below the surface of Pennsylvania, New York, West Virginia, and Ohio, has not only been the largest source of shale gas since 2013, it is one of the two major shale plays (the other play being the Utica) listed in Figure 1 that has seen consistent production growth in the face of recently depressed natural gas prices. In regards to Ohio, Marcellus shale development has been limited, with most exploration focusing on the richer, shallower parts of the formation in Pennsylvania. However, development in this region served as a precursor for resource exploration in the Eastern portion of Ohio, particularly in the Utica shale play. The Utica is a deeper shale formation than the Marcellus (around 7,000-10,000 ft. below the surface); the additional costs of extracting oil and gas from this depth were mitigated as productivity gains and costs reductions were realized in the drilling industry. Beginning in 2013, natural gas production in Ohio centered on the Utica shale play increased exponentially, growing from a meager 7,000 MMft^3 of production per month to around 113,000 MMft^3 in late 2015 (EIA 2016). The latter figure places Ohio 9th in state level natural gas production in the United States; given that production growth in Ohio has been the largest in the nation in 2016, it seems likely that Utica shale withdraws over the coming years will elevate this ranking.

Figure 2: Overview of Potential Shale Development Areas

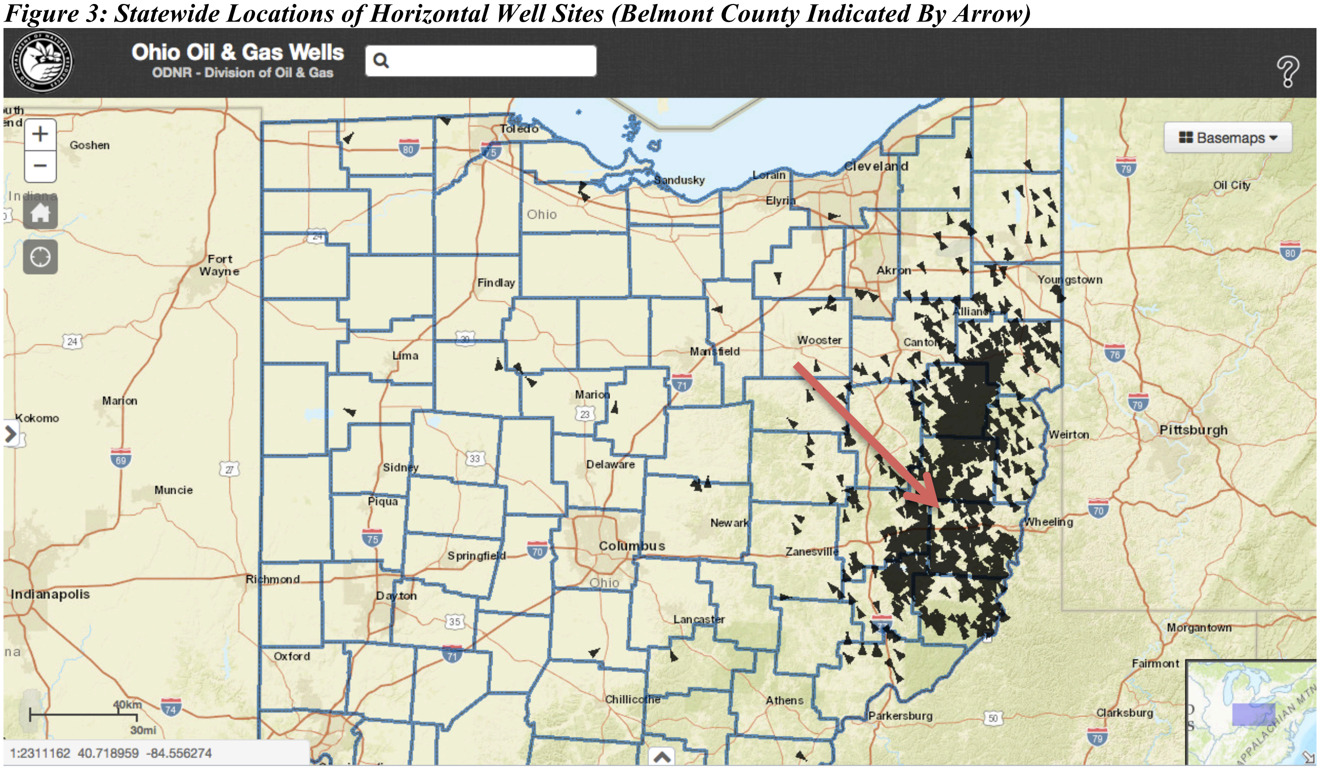


Source: Ohio Geological Survey (2012)

The extent of Ohio that resides above the Utica play can be seen in Figure 2 above. The shaded region of the map represents the extent of the state within the core production area of the

Utica shale play, as determined by the total organic content of rock samples in combination with other measurements of hydrocarbon potential (OGS 2012). Shading shows the vitrinite reflectivity of regional core samples; R_O ratings between 0.6 and 1.5 represent potential crude and wet natural gas reserves, while more mature ratings (greater than 1.5) represent potential dry natural gas reserves. As seen in the figure, much of the area that may be targeted for production is in the Eastern portion of the state. So far, most shale gas production has been concentrated in the Eastern-most counties shown in the core productive area in Figure 2. As of April 2016, over 1,700 horizontal wells have been drilled in the state, with an additional 400 wells permitted. The spatial distribution of these well sites can be seen in Figure 3 below.

Figure 3: Statewide Locations of Horizontal Well Sites (Belmont County Indicated By Arrow)



Source: Ohio Department of Natural Resources Oil and Gas Well Locator (2016)

Background: Overview of Shale Gas Production Process and Split Estates

Current shale gas production techniques incorporate a series of innovations in the extraction industry that occurred in the decades prior to Mitchell Energy's development; these technologies include horizontal drilling, hydraulic fracturing, and 3-D seismic mapping (NTEL 2007)(Wang and Krupnick 2013). Once a potential reserve has been located, a permit from the Ohio Department of Natural Resources has been secured, and the proposed location has been prepared with the proper safety equipment and storage tanks, a drilling rig is erected and drilling can commence. Drilling occurs roughly around six months after the permitting process is completed, and the drilling itself is typically completed in a span of 10 to 30 days, depending on the shale depth at the drilling location and other geologic characteristics (ODNR 2016).

Wells are drilled vertically downward at first, with steel casings secured by layers of cement are placed within the well bore in order to protect groundwater resources from brine contamination; Ohio law mandates that at least four steel casings must encompass each horizontal well bore (Ohio Revised Code 1509.17). As the shale formation is approached, the drilling angle is gradually shifted horizontally, targeting the relatively thin shale formation of interest. The thickness of the Ohio portion of the Utica formation ranges from around 150 ft. to 350 ft., with the thickest parts of the formation found in southeast Ohio (OGS 2012). Therefore, given the relative thinness of the shale formation, drilling the well horizontally maximizes the gas reservoirs accessible by a single well. After the bore has been completed, brine composed of water, sand, salts, and other chemicals is forced into the bore to expand fractures that developed around the bore. Hydrocarbons released from the shale formation flow back to the surface, as the fracturing fluid is rescinded back to the surface from internal pressures in the shale formation (EPA 2016).

Shale wells have become increasingly productive over the last decade. Around 8-10 wells can be drilled from a single surface well pad (Gopalakrishnan and Klaiber 2013)(Ohio Department of Natural Resources 2016), and each well can extend 1-2 miles from the well pad; according to the EIA, new well gas production per day in 2016 averages around 11,000 ft^3 per day, up from only 2,000 ft^3 per day in 2011. The productivity of each well diminishes greatly after the first year or two after the original fracturing, requiring additional refracturing to maintain high production levels (Boslett, Guilfoos, and Lang 2016). Each well uses around 15-20 thousands cubic meters of water to fracture the formation; water is reused in subsequent refracturing. The drilling and fracturing process is accompanied by large amounts of truck traffic, noise from drilling rigs, visual impairments, and other local disamenities. Local effects of exploration and drilling will be discussed in further detail in later sections.

Background: Split Estates and Royalty/Lease Payments

Before any permitting, drilling, or exploration can occur however, the drilling firm must acquire the mineral rights to the land parcel of interest. The mineral rights can be purchased outright, for a lump sum fee, giving the purchasing firm rights over the minerals indefinitely. Alternatively, the mineral rights can be leased from the landowner for a defined period of time. Terms of leasing agreements vary, in regards to both the pecuniary and environmental aspects of drilling; a study conducted on the value chain of a Marcellus wellhead discovered an average per acre leasing payment of $2,700 (Hefley et. Al 2011). Early rushes to secure mineral rights in Eastern Ohio led to payments hovering around $4,000 per acre (Hunt 2011). While these leasing payments occur only once, at the time of lease signing, other financial benefits accrue to rights holders over the course of shale development. Additional financial benefits that lessors incur include royalty payments on the value of gas produced from their minerals, free gas from producing wells, and additional payments for surface construction, provided that the lessor owns the surface property in the latter case. While surface remediation from alterations directly from the construction of the well pad and accompanying facilities is required by Ohio law after the drilling process has ended (Ohio Revised Code 1509.072), any further recuperation of local costs to a surface property owner are highly dependent upon the terms of the lease or sale (Timmins and Vissing 2015).

Notably, it is possible that a surface rights owner has no control over the mineral rights under their property, due to a past severance of the mineral rights from the property by the time of purchase. In this case, the mineral developer or third party attempting to secure mineral rights must seek out the entity in possession of these severed mineral rights in order to secure them for gas exploration and extraction. Again, the rights of the subsurface owner take precedent in this case. Split estates are most typical in regions of the nation that have experienced past development of subsurface resources (Weber and Hitaj 2014)(Timmins and Vissing 2015). Localized costs from shale gas exploration will accrue to these property owners, while the main benefits of shale production, the large royalty payments for the rights to extract minerals under the property, will accrue to other parties unrelated to the owner of the surface rights. Therefore, any changes to the value of the property once a particular region is inundated with shale development will not include one of the major benefits of that production to local landowners.

The preceding observation motivates this paper's research; how does the severance of the mineral rights from a parcel of land impact the value of the split estate in the land market? How does the implicit value of subsurface ownership embedded in land prices compare to the explicit market value of mineral rights? Do these impacts on the value of the land change over time, as more interest is generated in developing subsurface resources and more information is diffused about the ownership of oil and gas rights? This paper utilizes a hedonic model to attempt to evaluate the costs of a split mineral parcel to the market value of the surface property. The following literature review explores the potential costs and benefits to local communities, residents, and landowners from the development of shale resources. A brief exploration of hedonic theory is included, providing the framework for the quantitative portion of this paper. The methodologies and conclusions of pertinent research exploring the real estate impacts of natural gas exploration are then catalogued in order to shed light on how the econometric model of this paper should be specified and on what functional form should be assumed.

Literature Review

Ever since Mitchell Energy’s success in the Barnett shale play, a significant amount of literature has been produced on the impact of shale gas development on a series of economic topics. Robust summaries of these economic impact analyses are contained within Mason, Muehlenbachs, and Olmestead (2015) and Kinnaman (2010). One of the most highly touted benefits of shale gas development is increased employment for local and regional economies. This benefit seems to be corroborated in the literature, though the scale of these benefits does vary within the literature. Weber (2012) studies counties in Texas, Colorado, and Wyoming, three states that saw increased natural gas production early in the 2000’s, to examine the employment effects of shale development. Weber finds that shale development leads to modest increases in employment, wages, and median household income, though the magnitude of these benefits is much lower than those claimed by industry proponents. A more recent study, Feyrer (2014), utilizes a sample of all U.S. counties and finds a similar result; both studies find that for each million dollars of oil and gas extracted, around 2.5 jobs in the region around the county of production are created.

Concerns with "Dutch Disease", where increases in demand for employment in the oil and gas sector lead to higher wages for employees in the tradable sectors of a local economy, leading to contractions in a longer term growth industry, are conflicting in the literature, with some studies finding either zero or a positive effect on tradable goods and other local sectors (Maniloff and Mastromonaco 2014) (Fetzer 2014), and others identifying some indications of "Dutch Disease" (DeLeire, Eliason, and Timmins 2014). Public revenues are also positively impacted by shale gas development, again varying with local policies and conditions. Raimi and Newell (2014) find that local revenues in magnitude from 1-10%, depending on the existence of items such as local impact fees and mineral property taxation. Weber, Burnett, and Xiarchos (2014) find that increased revenues from oil and gas property taxation led to a sustained appreciation in home values of shale regions versus non-shale regions, potentially due to reductions in surface property tax rates and increased funding for local students.

The costs of shale gas development mostly focus on the negative externalities of mining activities. On a global scale, fugitive methane emissions may be at a scale that renders any direct reductions in carbon emissions moot; estimates for the extent of methane leakage range from around 2% (EPA 2014) to almost 8% (Howarth 2014). On a more local level, however, shale gas production has been linked to potential water contamination (Osborn et al 2011) (Jackson et al 2013) (Olmstead et al 2013) and local air pollution (McKenzie et. al 2014), each leading to potential health effects. Again, a robust summary of the literature regarding environmental externalities can be found in Mason, Muehlenbachs, and Olmstead (2015).

Given these positive and negative impacts of local shale development, the question remains as to how these impacts are reflected in the market value of real estate in regions of shale gas development. Muehlenbachs et al (2012) is one of the first attempts to explore real estate responses to shale development. This research focuses on a county south of Pittsburgh, Pennsylvania (Washington County) that was the site of intensive shale gas development in the early days of Marcellus exploration. The researchers utilize a triple difference framework, differencing across time, across treatment space (shale proximate vs. non shale proximate census tracts), and across water supply in order to test if the market response to shale development depended on the source of water for the home. Controlling for local demographics and other specific property characteristics, they find that proximity to shale development leads to an overall appreciation of home values, but there exists a significant market penalty for groundwater homes of around -23%.

Expanding on the findings of Muehlenbachs et al (2012), Gopalakrishnan and Klaiber (2013) continue to explore the housing market response to local shale development in Washington County, Pennsylvania. Controlling for the water supply of the home, Gopalakrishnan and Klaiber (2013) also incorporate varying temporal and spatial buffers for calculating the density of shale development around a home at the time of sale. The authors estimate the temporal persistence of local disamenities from shale production based upon the average production process of a shale well; time buffers reflect the persistence of various visible and audible disamenities common during the drilling process. Spatial buffers are generated from estimates on the visual range of drilling rigs and the length of typical wells. Land cover characteristics of the surrounding area are also included and interacted with well counts to test the impact of surface characteristics on the response to shale development. In contrast to Muehlenbachs (2012), a square root functional form is used for the hedonic model, instead of a semi-log form. Calculating shale well density with varying distance buffers of 0.75, 1, and 2 miles and with varying temporal restrictions, Gopalakrishnan and Klaiber (2013) find large, negative impacts of proximate shale wells permitted in the 6 months prior to the house sale, but the extent of these effects disappear as the temporal and spatial buffers are expanded. Additionally, the negative impacts of shale well density were more pronounced for homes surrounded by agricultural land.

The authors of both of the preceding studies note that the lack of leasing and mineral rights data is a significant omitted variable in determining the true cost of shale development on the average home. In order to nullify the effect of split estates, Boslett, Guilfoos, and Lang (2016) focus on counties along the New York-Pennsylvania border, an area where historical development of subsurface resources was limited. In this region, it can be assumed that the surface landowners typically own subsurface mineral rights. Leveraging the New York State moratorium on fracking, the authors exploit a discrete change in the expectations of future royalty payments after the declaration of the moratorium to value the difference in property values between border counties in New York and Pennsylvania. The researchers establish that geologic, economic, and demographic characteristics of regions adjacent to the border are similar, past trends in housing prices are parallel, and that labor and environmental spillovers from shale production in Pennsylvania are minimal. This allows a difference-and-difference model framework to be utilized along this border discontinuity in order to value the difference in property values for the treated (Pennsylvania) and untreated (New York) region. The difference-and-difference estimator's sign is determined by which local effects dominate; the environmental disamenities of shale production or the benefits of royalty and leasing payments. The authors find a significant difference in property values between properties in each state, with Pennsylvanian properties exhibiting a 23% appreciation in value compared to their New York counterparts.

With positive effects from shale gas exploration discovered in areas with few split estates, and the opposite for areas with higher levels of split estates, there is room within the literature to explore the effects of split estates on property sales. Weber and Hitaj (2014) use hedonic techniques to value the effects of shale development on agricultural land sales in the Barnett shale region and the Marcellus shale region. In both regions, the authors find appreciation in land values during the permitting stage of shale development, with insignificant levels of impact on land prices during the production stage of development. Appreciation was higher in the Marcellus shale, indicating that split estates are less common in the region. According to data on property tax records assembled by the researchers, this is probably the case, with split estates seemingly almost twice as common in the Barnett region versus the Marcellus region. Again, the lack of leasing data renders a direct valuation of mineral rights ownership difficult.

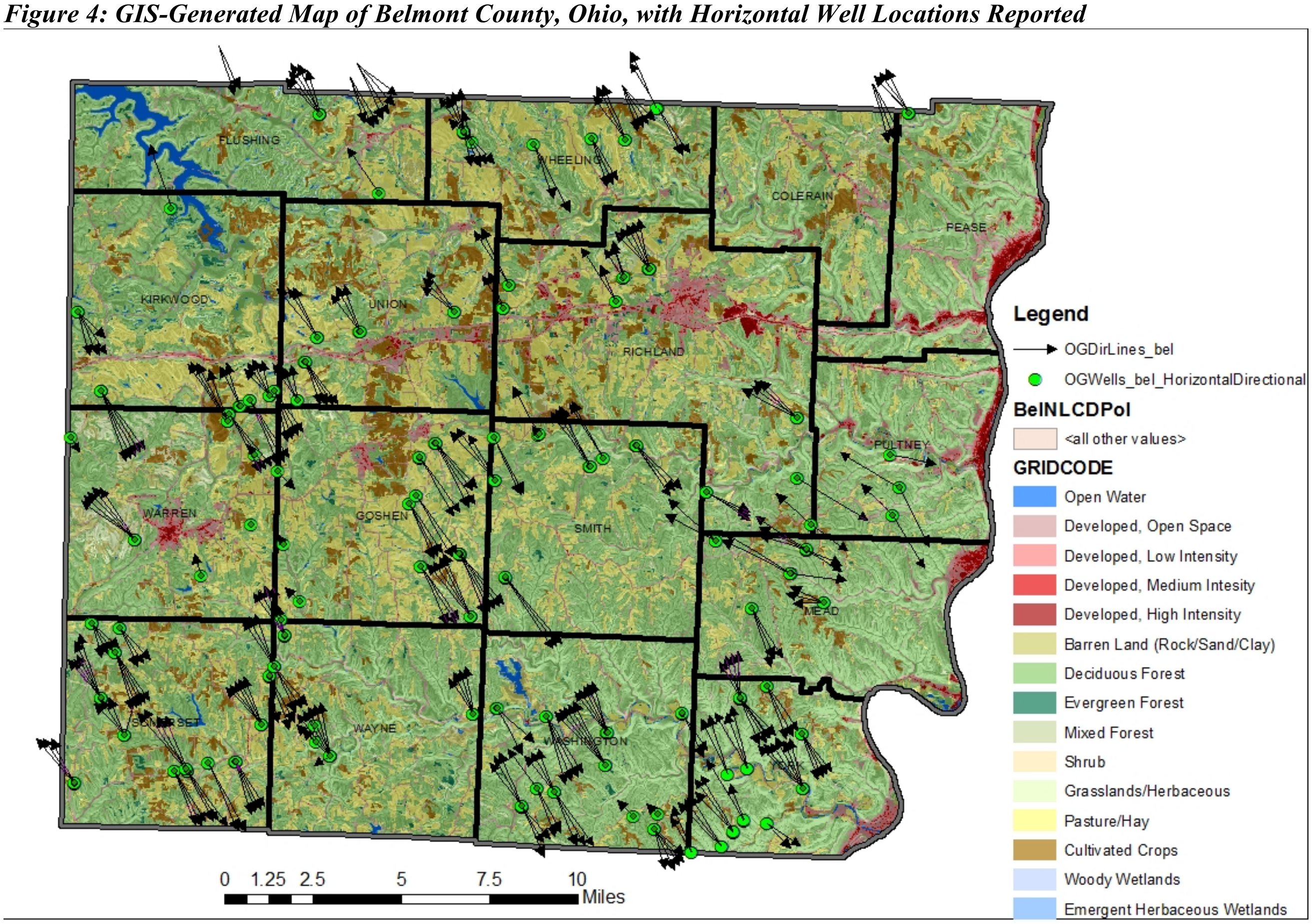
Only one paper was found that attempted to capture differences between properties with and without severed mineral rights at the time of sale. Timmins and Vissing (2015) utilize leasing data from a private data vendor in conjunction with transfer records to attempt to evaluate market prices for different types of ancillary lease clauses, such as surface or road remediation clauses, negotiated into the leasing terms by the rights holder. In their data set, they also generate an estimated dummy variable indicating whether or not the mineral estate was likely split at the time of sale for a particular property. A duel gradient hedonic model is utilized to account for split versus non-split properties. To generate variables on lease clauses, Timmins and Vissing use Python to search lease clauses for particular key words such as “Surface Damage” and “Environmental”. In order to generate their split estate identifier, lessors and lessees in their lease sample are matched with the names on property transfer deeds, again using string-matching algorithms written in Python. Their methodology for identifying split estates informs the methodology used in this paper.

The findings of this literature review, as shown by the papers discussed above, indicate that a reduced form hedonic model is the best approach for evaluating the value of a property characteristic. Hedonic models, as outlined by Rosen (1974) and discussed in Taylor (2003) assume that the interactions of many buyers and sellers acting in a competitive market determine an equilibrium price schedule for a differentiated commodity good, *Z*. This commodity good is composed of various characteristics; in the agricultural land market, characteristics can include soil productivity, slope, etc. An individual maximizes their utility by selecting the differentiated good and a composite commodity good, X, where X represents all other goods, subject to a budget constraint. This occurs where the marginal rate of substitution between a characteristic comprising Z and the composite commodity good is equal to the rate at which this characteristic can be traded for X in the marketplace. On the supply side, a firm seeks to maximize its profits by selling a version of Z to consumers subject to a cost constraint. The commodity price schedule is determined by the location on the price-quantity where each individual's bid and each firm's offer curves are tangent to each other, or the point where the marginal benefit of the quantity of the particular characteristic to the consumer is equal to the marginal cost of the supplier providing that good to the market. A marginal willingness to pay for a particular characteristic can be derived from regression analysis of the market prices of particular goods; the implicit price of each characteristic represents the average marginal willingness to pay for that particular characteristic.

In order to evaluate the willingness to pay for a property with a split estate, the characteristics that buyers seek when purchasing agricultural land must be sought out. These include structural characteristics of the land being sold or the existence of a split estate, such as its soil productivity and land cover, locational characteristics of the land, such as the distance to a state road or municipality, and neighborhood or regional characteristics, such as the density of well development in a region. Ideas for explanatory variables related to the sale of agricultural land are identified through discussions with relevant faculty and prominent papers in the field. The following sections describe the location that land transaction data describe, as well as the source of each of the variables constructed for the study.

Overview of the Region of Study

Figure 4: GIS-Generated Map of Belmont County, Ohio, with Horizontal Well Locations Reported



Source: Various Sources

Belmont County is a relatively large county along the Ohio River in Eastern Ohio. According to the 2010 United States Census, the county's population is 70,040, with a median household income of $43,045, just slightly below the state average. Heavy population centers are along the Ohio River and along Interstate 70, which runs east-west across the county. The county seat, St. Clairsville is along this stretch of development. The county is covered mostly in deciduous forest, which comprises over 50 percent of Belmont County land cover. In regards to demographics, the county is relatively homogenous, with almost 95 percent of its population identified as “white only”. Additional statistics about the county’s land cover, as well as population at the township level can be seen in the two tables below.

Table 1:Belmont County -- Township Overview

Township	Population	Area (sqmiles)	Horiz. Well Count
PEASE	14961	28.86	4
RICHLAND	13571	58.44	27
PULTNEY	9700	26.58	5
MEAD	6023	32.07	16
WARREN	5870	35.23	16
COLERAIN	4438	24.95	0
GOSHEN	3252	36.51	27
YORK	2648	25.87	40
UNION	2151	35.36	17
FLUSHING	1990	31.11	6
WHEELING	1477	27.52	22
SMITH	1445	36.46	21
SOMERSET	1186	34.79	51
WAYNE	624	35.49	23
WASHINGTON	537	36.05	40
KIRKWOOD	353	36.73	23
Total	70226	542.02	338

Table 2: NLCD 2011 Belmont County Land Cover	
Land Use Type	Percentage of County
Open Water	1.17%
Developed, Open Space	6.91%
Developed, Low Intensity	1.51%
Developed, Medium Intensity	0.74%
Developed, High Intensity	0.27%
Barren Land	1.07%
Deciduous Forest	57.10%
Evergreen Forest	0.71%
Mixed Forest	0.01%
Shrub	0.14%
Grasslands/Herbaceous	3.25%
Pasture/Hay	21.16%
Cultivated Crops	5.85%
Woody Wetlands	0.09%
Emergent Herbaceous Wetland	0.04%

Data

Data on land transfers and tax parcels within the county were purchased from the Belmont County Auditor Office. The dataset included records on land sales from 1998-2015 by parcel level, as well as some descriptions of characteristics of each tax parcel reported in the dataset. Characteristics provided for most tax parcels included house characteristics, such as the number of bedrooms, square footage of the property, the presence of a fireplace, etc., the size of the parcel in acres, the deeded owner of the parcel, and other various descriptors of the property. Transfer records included a unique transfer id number, the number and id's of tax parcels within each sale, the sales amount of the transaction, the individuals involved with the transaction, and other characteristics of the transaction. Importantly, the auditor designated use code of each tax parcel was included in the dataset. This identifier was used to generate a list of transfer id's corresponding to transactions involving agricultural land sales. Agricultural land sales are used for two major reasons. Firstly, limiting the sample to agricultural sales reduces the sample to a manageable level, relieving a large amount of workload in split-estate identification. Secondly, agricultural land parcels are typically larger parcels, making them easier to uniquely identify using surface characteristics. This is important, as this facilitates an easier identification process for attempting to locate the corresponding subsurface tax parcel. Land transfers from 2013-2015 were identified, and the records for each tax parcel included in the sale were used to assemble total characteristics for each piece of land transferred. However, as the dataset was being assembled, it became clear that these use codes might have been assigned somewhat arbitrarily, which may have acted as a source of bias in the results.

Characteristics that could not be derived from the auditor tax data were assembled utilizing Geographic Information System (GIS) processing software. Fortunately, Belmont County provides interested individuals geographic data in vector format of surface tax parcels, allowing for surface characteristics to be derived in ArcGIS. The Belmont County GIS office also provides shapefiles for townships and Public Land Survey System (PLSS) sections free on their website. Data on land cover was assembled from the National Land Cover Database created by the United States Geological Survey. Average slope gradients for each parcel included in land transfers were calculated using elevation data from the National Map. Data on soil type and productivity were sourced from the United States Department of Agriculture's SSURGO soil database. The National Commodity Crop Productivity Index, which assigns ratings based on soil characteristics conducive to growing mainstay commodity crops such as corn, soybeans, and wheat, provided metrics to assign to the spatial data on soil types. Ratings are assigned on a 0 to 1 scale, with a rating close to 1 indicating high suitability for commodity crop production. The data also contains a similar variable describing land potential for grazing, created with the Pasture and Hayland Suitability Group. This framework groups soil types into different categories of pastureland, based on their suitability for the conditions of grazing and similar activities. Data on the location of state roads was obtained from the Ohio Department of Transportation in order to generate distance to state roads variables for each land sale. Finally, oil and gas well data was obtained through the Ohio Department of Natural Resources. This dataset included dates on permitting, drilling, and production dates, though much of the GIS data had to be supplemented with further data on wells from a separate ODNR database. Well data was obtained for both historical vertical well sites and more recent horizontal drill sites. Well densities, both permitted and producing, with varying spatial buffers of 1 and 2 miles were created. Controls for shale richness were also generated using data from the Ohio Department of Natural Resources. To control for region-specific unobservable, township-level fixed effects were created for townships with high levels of drilling activity.

The variable of interest, a dummy variable indicating whether or not a surface parcel was split from the subsurface mineral parcel, was quite difficult to obtain. While the auditor data provided some data on mineral rights parcels in existence in the county, there was no strong identifier of geographic location of these mineral rights parcels, other than the Public Land Survey System (PLSS) section that this mineral parcel was located under. The PLSS provides a sectional grid of the county, with each PLSS section approximately 1x1 mile, or 640 acres, in size. This PLSS identifier was inconsistently reported, though for most parcels, it provided some resolution as to the parcel's geographic location. Also included were the transfer history of each mineral parcel and its acreage. Without direct geographic identification of the location of these parcels, identifying whether or not a surface parcel corresponded to a split mineral parcel at the time of sale required matching the acreage of the surface parcel with the acreage of the mineral parcels of each section. Unfortunately, mineral parcels were created as they were purchased, meaning that if a large sale of mineral parcels occurred, with multiple surface owners selling their mineral rights at once, the mineral parcel that was created corresponded to the sum of all of these individual parcels. Also, given the historical development of subsurface resources in the region, many mineral parcels derived from surface parcels harkening back decades, which in many cases were larger amalgamations of current tax parcels.

Despite these limitations in the data, matching acreage and deeded land owners for surface properties with the transfer records of mineral parcels provided some clear-cut examples of split estates. Luckily, the Ohio Dormant Minerals Act states that if subsurface rights are not exercised through production or the creation of a tax parcel, among other things, the rights to these subsurface minerals revert back to the surface landowner (Ohio Revised Code 5301.56). Therefore, it can be assumed with confidence that instances of mineral parcels that were severed from their surface parcel, but do not show up in the auditor data, are minimal. However, it is almost certain that a large portion of the split estates within the dataset remain unidentified, due to measurement error on the researcher's part, as well as the uncertainty created by mismatches between mineral parcel sizes.

Only 19 instances of split estates could be identified conclusively. Land transfers with sales amounts in the tails of the distribution were removed from the dataset; tails were clipped at the fifth and ninety-fifth percentiles. Transactions with inconsistencies in the auditor dataset were also dropped. Inconsistencies were generally errors in measurement or reporting, such as non-matching entries for sales amounts, acreage, etc. across transaction recordings and tax parcel recordings. After these removals, a final dataset of 190 transactions, out of 223 total sales, was assembled from the auditor records. Summary statistics for this final dataset can be found in Table 3 and Table 4 below.

Table 3:Total Observations by Township/Year (Total Obs: 190)								
Township	COL	FLU	GOS	KIR	MEA	PEA	PUL	RIC
Obs.	8	9	14	2	9	9	16	17
Township	SMI	SOM	UNI	WAR	WAS	WAY	WHE	YOR
Obs.	11	22	25	14	10	15	6	3
Year: 2015				48				
Year: 2014				81				
Year: 2013				61				

Table 4: Summary Statistics					
Variables	Units	Mean	Std. Dev.	Min	Max
Sales Amount	2015 $	178268.6	259219.2	2152	2484400
Acreage of Land	Acres	41.14	44.27	1.01	209
Home on Sold Land	Dummy (1 if yes)	0.421	0.495	0	1
Home Age	Years	24.39	44.27	0	183
Home Bedrooms	# of Bedrooms	1.29	1.63	0	5
Home Square Footage	Square Feet	762.27	1180.9	0	8963
Permitted Hori. Well Density within 1 Mile	# of Wells	1.39	2.89	0	21
Producing Hori. Well Density within 1 Mile	# of Wells	0.89	2.08	0	16
Permitted Hori. Well Density within 2 Mile	# of Wells	4.24	6.17	0	38
Producing Hori. Well Density within 2 Mile	# of Wells	2.86	4.69	0	26
Dist to State Rd.	Miles	0.509	0.524	0	2.23
Dist to Municipality	Miles	2.5	2.03	0	7.41
Avg. Soil Productivity Rating	Index from 0-1	0.385	0.149	0	1.07
Group-A Pasture Land	Dummy (1 if yes)	0.737	0.4415	0	1
Average Slope	Degrees	8.7	3.35	1.81	20.08
Split Estate at Sale	Dummy (1 if yes)	0.105	0.308	0	1
Vertical Wells within 1 Mile	# of Wells	30.1	38.5	0	246
Vertical Wells within 2 Mile	# of Wells	87.71	84.69	0	557
%Water	% of Total Area	0.0022	0.012	0	0.13
%Developed	% of Total Area	0.077	0.14	0	0.95
%Barren	% of Total Area	0.0048	0.029	0	0.32
%Forest	% of Total Area	0.62	0.34	0	1
%Agriculture	% of Total Area	0.27	0.31	0	1
%Grasslands	% of Total Area	0.024	0.051	0	0.3
%Wetlands	% of Total Area	0.0001	0.0015	0	0.02

Methodology

As stated above, a hedonic model is utilized to discover average marginal willingness to pay for the explanatory variables listed above. After running a series of preliminary regressions, a semi log functional form is utilized for all reported regressions; this is the most common choice of functional form in the hedonic literature of this topic area (Muehlenbachs 2012) (Weber and Hitaj 2014). As a simplified linear form of the general hedonic equation, the following equation describes the hedonic equation as specified in the reported regressions:

$$\ln SalesAmount = \beta_0 + \delta * SplitEstate_i + \sum_{k=1}^{h} \beta_k H_i + \sum_{m=1}^{l} \beta_m L_i + \sum_{p=1}^{n} \beta_p N_i + \tau + \alpha + \epsilon_i$$

where δ represents the percentage impact of a split estate on the sale price of the land, H_i, L_i, and N_i represent structural, locational, and neighborhood characteristics of each individual land sale *i*, and a set of fixed effects for the year of sale and for sales in the four townships where shale gas development is most extensive (Washington, Somerset, Goshen, and York). Given the findings of the literature review, there seems to be a significant penalty to surface properties that are no longer in possession of the subsurface rights. Therefore, it is hypothesized that the coefficient δ would be negative and relatively severe; impacts of proximate shale gas development on properties in regions of historical development were upwards of 20-25 percent of the average property value in much of the literature review. A testable hypothesis can be described by the following; the hedonic model stated above is utilized to test the null hypothesis that split estates have no impact on the market value of an agricultural land parcel.

The density variable for permitted and producing shale wells is varied in each specification, in order to control for the effects of proximate shale development. As one moves further away from an agricultural land parcel, the negative disamenities of shale gas production should dissipate, as seen in Klaiber and Gopalakrishnan (2013). It is hypothesized that permitted well density will be positively correlated with the sales amount of the property, especially for the two-mile density variable. In this case, the negative externalities of shale production have mostly decayed, while high well permitting within a one or two-mile distance of a property can signal potential leasing and royalty payments in the coming months (Weber and Hitaj 2014). Alternatively, a less positive impact was expected for the producing well density variables, as a higher density of producing wells indicates that the leasing period is mostly over, and that windfalls from regional gas development have probably subsided.

Also included are the controls for the agricultural potential of the land; soil productivity, pasture rating, and average slope gradient. The signs of these variables of the first two were expected to be positive, due to the current usage of the land. High slope gradients should have negative affects on the value of the land, as this limits the land's productive use for agriculture and other forms of economic development. Distances to the nearest state road and municipality are included to control for locational attributes of the land parcel; given that distances are not specified as inverse distances in this dataset, the expected sign of these coefficients was negative. Farmers, non-farmers, and shale developers alike should want to reside close to access roads and markets. The existence of a residence on a property as well as any increases in the size or robustness of a residence were expected to increase the value of the property. A dummy variable for the existence of a home on the property is included, with variables for bedrooms, square footage, and age describing the residence. A few alterations were made to the variables regarding land cover. Due to the small size of the *%water* and *%wetlands* variables, these are added together and represented as a single variable, *%other*. Also, in order to avoid perfect collinearity of explanatory variables, the land cover variable *%agriculture* is dropped from the regressions.

The expected value of *%grasslands* was positive, with uncertainty regarding the effects of other land cover types. Tests for heteroskedasticity (Breusch-Pagan) signal no significant problems with inconsistent variances in all reported regressions; no additional actions are taken to deal with potential heteroskedasticity in the data set, as per the results of these tests.

Results

Regression results are reported in Table 5 below. In the reported specifications, as well as the countless others that are not reported in this paper, *SplitEstate* is consistently insignificant. Therefore, this analysis fails to reject the null hypothesis that there is no effect from a severed estate on the market value of agricultural land; a willingness-to-pay (WTP) estimate cannot be generated. However, the density of permitted wells was significant and positive for the two-mile density buffer. This supports the findings of Weber and Hitaj (2014), who found that permitted well density positively impacted agricultural land prices. For every marginal increase in permitted wells within a two-mile buffer, the average agricultural parcel appreciates 8 percent in market value, according to the results. This finding was found to be significant at only the 10 percent level. Acreage also exhibits a strong positive correlation, as well as acreage squared. The yearly fixed effect for 2015 is also positive and significant. This makes sense, as most shale activity has occurred in 2015, implying upward pressure on the housing and land market due to economic activity in the region. Further analysis does show, however, that interacting permitted well density with the 2015 or 2014 dummy variable does not lead to any different findings; the coefficient permitted well density in a two mile buffer is consistently significant and positive across all time periods. As for the other variables included in the regression, most are not found

Table 5: Split Estate Regression Results Dependent Variable: Log *Sales Amount* w/ Standard errors in parentheses $^{*}\ p < 0.10$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$					
Variable	1 Mile Buffer	2 Mile Buffer	Variable	1 Mile Buffer	2 Mile Buffer
Acreage	0.0246***	0.0247***	**A Group Pastureland (1 if A)**	0.125	0.0863
	(-0.00605)	*(-0.00606)*		*(-0.189)*	*(-0.188)*
Acreage^2	-0.0000871**	-0.0000935**	**AverageSlope (Degrees)**	-0.0126	-0.0172
	(-0.0000396)	*(-0.0000393)*		*(-0.0347)*	*(-0.0351)*
Home on Sold Land	0.324	0.32	**Split Estate at Sale**	-0.0293	-0.0436
	(-0.383)	*(-0.381)*		*(-0.265)*	*(-0.268)*
Homesoldsqft	0.000245	0.000254	**Permitted Well Density 1Mile**	0.0961	
	(-0.000254)	*(-0.000255)*		*(-0.0907)*	
Homesoldsqft^2	-2.10E-08	-2.15E-08	**Producing Well Density 1 Mile**	-0.0314	
	(-3.11E-08)	*(-3.13E-08)*		*(-0.121)*	
Homesoldage	0.000554	0.000618	**Permitted Well Density 2Mile**		0.0870*
	(-0.00243)	*(-0.00245)*			*(-0.0475)*
%Developed	0.165	0.166	**Producing Well Density 2mile**		-0.0822
	(-0.641)	*(-0.639)*			*(-0.0614)*
%Barren	-2.641	-1.855	**2015**	0.425*	0.419*
	(-2.775)	*(-2.717)*		*(-0.216)*	*(-0.231)*
%Forest	0.0118	0.0307	**2014**	0.204	0.202
	(-0.282)	*(-0.281)*		*(-0.178)*	*(-0.18)*
%Grasslands	1.376	1.35	**WASHINGTON**	-0.0238	-0.00555
	(-1.542)	*(-1.545)*		*(-0.375)*	*(-0.377)*
%Water/Wetland	-15.93**	-16.39**	**SOMERSET**	-0.184	-0.115
	(-6.706)	*(-6.701)*		*(-0.301)*	*(-0.31)*
Dist to State Rd.	0.126	0.111	**GOSHEN**	0.369	0.425
	(-0.157)	*(-0.159)*		*(-0.298)*	*(-0.305)*
Dist to Muni (miles)	0.0434	0.0439	**YORK**	0.709	0.742
	(-0.047)	*(-0.0472)*		*(-0.621)*	*(-0.623)*
Avg. Soil Productivity Rating	-0.0282	-0.219	**Constant**	10.00***	10.11***
	(-0.661)	*(-0.658)*		*(-0.559)*	*(-0.56)*
			R^2	0.433	0.429
			Adjusted R^2	0.346	0.342

to be significant. Importantly, variables related to the agricultural productivity of the land parcels are also consistently insignificant. In regards to land cover, there is a strong, negative impact of water on a property (in the second specification); a percentage increase in land cover classified as water or wetlands leads to a 16 percent decrease in the average agricultural land parcel's market value.

Given these findings, and the lack of significance of the split estate indicator, an indirect indicator of split estates was used in replacement of the split estate dummy variable in order to capture whether or not any discernable relationship between split estates and sales prices could be discovered in the data. The density of past vertical well drilling can be expected to act as a proxy for split estates; past development in a region implies past mineral parcel sales. The vast majority of vertical wells drilled in Belmont County are no longer producing wells, nor do the geological conditions that make vertical well drilling applicable apply to horizontal drilling. Therefore, it can be argued that historical vertical wells may solely impact current agricultural land sales through their impact on mineral rights. Using the same specification as the previous regressions, and varying the vertical well density buffer from one to two miles, this hypothesis was tested via another pair of hedonic regressions. Results from this second pair of regressions can be found in Table 6 of this paper below. Interestingly, variables indicating vertical well density in one and two mile buffers around sales parcels were also insignificant. For the most part, there was no movement in the coefficients of the explanatory variables when vertical well density was added to the equation. Various interactions between vertical well densities and yearly fixed effects came up as insignificant as well, though these regressions are not reported in this paper.

Table 6: Vertical Well Proxy Regression Results					
Dependent Variable: Log Sales Amount w/ Standard errors in parentheses* p < 0.10, ** p < 0.05, *** p < 0.01					
Variable	1 Mile Buffer	2 Mile Buffer	Variable	1 Mile Buffer	2 Mile Buffer
Acreage	0.0249***	0.0253***	**AverageSlope (Degrees)**	-0.0123	-0.0202
	(-0.00609)	*(-0.00613)*		*(-0.0346)*	*(-0.0353)*
Acreage^2	-0.0000875**	-0.0000945**	**1MileVert Density**	-0.000774	
	(-0.0000396)	*(-0.0000392)*		*(-0.00223)*	
Home on Sold Land	0.313	0.306	**Permitted Well Density 1Mile**	0.0985	
	(-0.383)	*(-0.379)*		*(-0.0908)*	
Homesoldsqft	0.000256	0.000262	**Producing Well Density 1 Mile**	-0.0345	
	(-0.000255)	*(-0.000254)*		*(-0.122)*	
Homesoldsqft^2	-2.26E-08	-2.32E-08	**2MileVert Density**		-0.000663
	(-3.13E-08)	*(-3.13E-08)*			*(-0.00108)*
Homesoldage	0.000491	0.000529	**Permitted Well Density 2Mile**		0.0880*
	(-0.00244)	*(-0.00245)*			*(-0.0474)*
%Developed	0.176	0.194	**Producing Well Density 2mile**		-0.0838
	(-0.636)	*(-0.635)*			*(-0.0614)*
%Barren	-2.633	-1.758	**2015**	0.418**	0.401*
	(-2.774)	*(-2.715)*		*(-0.203)*	*(-0.215)*
%Forest	0.0214	0.0471	**2014**	0.203	0.202
	(-0.282)	*(-0.282)*		*(-0.176)*	*(-0.179)*
%Grasslands	1.414	1.408	**WASHINGTON**	0.0192	0.0713
	(-1.544)	*(-1.544)*		*(-0.397)*	*(-0.398)*
%Water/Wetland	-15.91**	-16.77**	**SOMERSET**	-0.176	-0.103
	(-6.673)	*(-6.676)*		*(-0.302)*	*(-0.311)*
Dist to State Rd. (miles)	0.129	0.109	**GOSHEN**	0.349	0.389
	(-0.156)	*(-0.158)*		*(-0.299)*	*(-0.305)*
Dist to Muni (miles)	0.0444	0.0496	**YORK**	0.718	0.746
	(-0.0469)	*(-0.0481)*		*(-0.621)*	*(-0.622)*
Avg. Soil Productivity Rating	0.0135	-0.186	**Constant**	9.984***	10.14***
	(-0.667)	*(-0.657)*		*(-0.561)*	*(-0.561)*
A Group Pastureland (1 if A)	0.125	0.0858	R^2	0.433	0.43
	(-0.188)	*(-0.187)*	**Adjusted R2**	0.346	0.343

Discussion and Directions of Future Research

Though the literature suggests that the existence of split estates leads to a mitigation of positive impacts of shale gas development on land prices, the attempts to direct identify this negative effect and evaluate its magnitude by this paper were unsuccessful. This lack of success may be attributed to a wide variety of potential biases and data limitations. First, the dataset constructed for this analysis contained only 190 observations, with only 19 identified cases of split estates within this sample. These 19 cases are identified as split estates with high certainty. However, given the sheer volume of mineral parcels recorded in the auditor tax records, it is unlikely that this proportion captures the true amount of split estates within the county. With limited geographical identification of mineral parcels, it is extremely difficult to pinpoint the extent of split estates within the county. Therefore, it is likely that these omitted split estates led to significant bias in the corresponding coefficient; intuitively, including land parcels with potentially split subsurface rights with non-split land parcels will understate the impact of an identified split estate.

Another issue that may be affecting identification might be selection biases within the sample of land sales; if there is limited interest in agricultural production in the region, as the findings of the hedonic analysis imply, then recent consumers of land in the area may have a preference for land that still maintains its subsurface rights. This issue of endogeneity is present in both methods of split estate identification described in the previous paragraph. This hypothesis is supported from observations taken during dataset assembly; when constructing the variable identifying split estates, there was an observed trend of mineral parcel creation and transfers for recently purchased parcels of land. In other words, very soon after the purchase of a given parcel of agricultural land, the subsurface rights to that parcel were severed and sold. It could be the case that the bundled good composed of both mineral and surface rights is of less value to those purchasing land in the area than the sum of the individual goods separately.

Finally, while findings on split estates were insignificant, this paper did corroborate the findings of the literature regarding the heterogeneity of shale gas impacts through different phases of the development process in a region. As stated above, significant appreciation of land values in more densely permitted areas can be an indicator of expected royalty or lease payments. While produced well density estimates were insignificant, they were close to significance at the 10 percent level at the two-mile buffer distance and negative in sign, implying that higher densities of producing wells is detrimental to the value of a property. This result could be due to the limitations of this particular analysis, but in most specifications, significance or near significance of this producing well density variable was discovered. It may be the case that producing wells are a signal of a region being "tapped out", with the lack of developmental interest in the region leading to a depression of the land prices of the region when compared to its less developed counterparts within a county, an issue that would arise in samples constructed in the midst of a shale boom.

Conclusions and Future Research

The shale gas production boom is underway in Ohio. Much of the benefits of this production to localities come from the direct payments for the use of mineral resources, either in the form of leasing or in outright purchasing of subsurface rights. Employment and other economic impacts of local production are marginal, and are highly temporal unless public entities seize the opportunity of local economic activity to raise revenues (Raimi and Newell 2013). Negative externalities, whether proven or perceived, can also accrue in regions of shale development. The net impacts that these forces have on landowners in the region depend upon the magnitude of these effects. While properties appreciate in value during the permitting and exploration stage, the findings of this paper potentially indicate an equal depreciation in these land holdings soon thereafter. It may be the case that, given the high rate of diminishing returns of local shale well production and the net neutral effects of gas development in the Ohio context, these leasing and royalty payments are the sole benefit that can persist beyond the short term in areas of shale gas development. In order to maximize the positive benefits of this development for local citizens, the mechanisms that determine the distribution of benefits and costs across different segments of the community need to be better understood.

The split estate question, whether the implicit land market value of subsurface ownership compares to the explicit market price, remains unresolved, but this paper suggests several avenues for future research. Given the data at hand, there may be ways to move forward in exploring impacts of split estates. While this paper attempted to directly value the marginal willingness to pay for a split estate in the land market, there are potential indirect methods of exploring this question in Belmont County. For instance, while the PLSS identifiers were too broad for parcel level identification and valuation of severed mineral rights, exploring the issue at a section level may deliver insights as to how different percentages of split estates in different sections impact housing and land transactions in each, controlling for other determinants of these transactions. Additionally, the results of this paper suggest there is a speculative period where appreciation in land values occurs, which is followed soon after by a rapid depreciation in prices when leasing rates have declined. This speculation story should also be explored in further detail. Finally, the propensity of firms to purchase full estates and split these estates soon after indicates that purchasing both the surface and subsurface rights of a land parcel, rather than acquiring only the subsurface rights, is a more valuable method of securing and selling mineral rights. There may be multiple mechanisms that explain this behavior, such as information asymmetry between land owners and royalty firms, and this paper recommends future research in this topic.

References

Boslett, A., Guilfoos, T., & Lang, C. (2016). Valuation of expectations: A hedonic study of shale gas development and New York's moratorium. *Journal of Environmental Economics and Management.* Retrieved April 07, 2016, from http://www.sciencedirect.com/science/article/pii/S0095069615001023

Energy Information Administration, (2015). Annual Energy Outlook 2015. Report. U.S. Department of Energy.

Energy Information Administration, (2016). Monthly Natural Gas Report March 2016. Report. U.S. Department of Energy.

Fetzer T. (2014). Fracking growth. CEP Discuss. Pap. Rep. 1278, Cent. Econo. Perform. Lond. Sch. Econ, Politic. Sci., London.

Feyrer, J., Mansur, E. T., & Sacerdote, B. (2014). Where's my fracking job? Geographic dispersions of economic shocks from hydrofracturing. *Work. Pap., Dartmouth College*.

Gopalakrishnan, Sathya, Allen Klaiber, H., (2013). Is the Shale energy boom a bust for nearby residents? Evidence from housing values in Pennsylvania. Am. J.Agric. Econ. 96 (1), 43–66.

Hughes, J. David, (2010). Drilling Deeper: A Reality Check on U.S. Government Forecasts for a Lasting Tight Oil & Shale Gas Boom. Post-Carbon Institute Paper.

Hefley, W.E., et al, (2011). The Economic Impact of the Value Chain of a Marcellus Shale Well. Working Paper, Katz Graduate School of Business. University of Pittsburgh. Pittsburgh, PA.

Howarth, R. W. (2014). A bridge to nowhere: Methane emissions and the greenhouse gas footprint of natural gas. *Energy Science & Engineering Energy Sci Eng, 2*(2), 47-60.

Maniloff P, Mastromonaco R. 2014. The Local Economic Impacts of Unconventional Shale Development. Work. Pap.

Marchand J. (2012). Local labor market impacts of energy boom-bust-boom in Western Canada. J. Urban Econ. 71(1):165-174.

Mason, C. F., Muehlenbachs, L., & Olmstead, S. M. (2015). The Economics of Shale Gas Development. *Resources for the Future*.

McKenzie, Lisa M., Witter, Roxana Z., Newman, Lee S., Adgate, John L., (2012). Human health risk assessment of air emissions from development of unconventional natural gas resources. Sci. Total. Environ. 424, 79–87.

Muehlenbachs, L., Spiller, E., & Timmins, C. (2012). Shale Gas Development and Property Values: Differences across Drinking Water Sources. Retrieved from http://www.nber.org/papers/w18390

Muehlenbachs, Lucija, Spiller, Elisheba, Timmins, Christopher, (2015). The housing market impacts of Shale gas development. Am. Econ. Rev. 105 (12), 3633–3659.

National Energy Technology Laboratory (NETL). 2007. DOE's Unconventional Gas Research Programs 1976–1995: An Archive of Important Results. Washington, DC: US Department of Energy. Available at www.netl.doe.gov/kmd/cds/disk7/disk2/FinalReport.pdf.

Ohio Department of Natural Resources. (2016). Ohio Oil and Gas Laws. Retrieved from http://oilandgas.ohiodnr.gov/laws-regulations/oil-gas-law-summary

Ohio Geological Survey. (2012). Geology and Activity Update of the Ohio Utica-Point Pleasant Play. Retrieved from http://geosurvey.ohiodnr.gov/portals/geosurvey/energy/Utica/Utica-PointPleasantPlay.pdf

Olmstead, Sheila M., Muehlenbachs, Lucija A., Shih, Jhih-Shyang, Chu, Ziyan, Krupnick, Alan J., (2013). Shale Gas Development Impacts on Surface Water Quality in Pennsylvania. Proc. Natl. Acad. Sci. 110 (13), 4962–4967.

Osborn SG, Vengosh A, Warner NR, Jackson RB. 2011. Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. Proc. Natl. Acad. Sci. USA. 108(20):8172–8176.

Raimi D, Newell RG. 2014. Oil and gas revenue allocation to local government in eight states. Durham, NC: Duke University Energy Initiative.

Rosen, Sherwin, (1974). Hedonic prices and implicit markets: product differentiation in pure competition. J. Polit. Econ. 82 (1), 34–55.

Taylor, L. O. (2003). The hedonic method. In. A primer on nonmarket valuation, ed. P. A. Champ, K. J. Boyle, and T. C. Brown, 331–393. Norwell, MA: Kluwer Academic.

Timmins, C., & Vissing, A. (2015). Valuing Leases for Shale Gas Development. Retrieved from http://www.tse-fr.eu/sites/default/files/TSE/documents/sem2015/environment/timmins1.pdf

Vissing A, Timmins C. (2014). Shale Gas Leases: Is Bargaining Efficient and What are the Implications for Homeowners if it is not? Work. Pap., Duke Univ.

Wang, Z., & Krupnick, A. (2015). A Retrospective Review of Shale Gas Development in the United States: What Led to the Boom? *Economics of Energy & Environmental Policy EEEP, 4*(1).

Weber JG, Burnett J, Xiarchos IM. 2014. Shale Gas Development and Housing Values over a

Decade: Evidence from the Barnett Shale. Work. Pap. 14-165., US Assoc. Energy. Econ. Cleveland, OH.

Weber, J., & Hitaj, C. (2014). What can we learn about shale gas development from land values? Opportunities, challenges, and evidence from Texas and Pennsylvania. Retrieved from http://purl.umn.edu/170596

Weber JG. (2012).The effects of a natural gas boom on employment and income in Colorado,Texas, and Wyoming. Energy Econ. 34(5):1580-1588.

Yergin, D. (2011). The quest: Energy, security and the remaking of the modern world. New York: Penguin Press.